

ACCRETION IN CATAclySMIC VARIABLE STARS

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Abstract We consider accretion onto the white dwarfs in cataclysmic variables in relation to nova eruptions, dwarf nova outbursts, hibernation and non-radial oscillations.

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The evolution of the surface temperature of an accreting white dwarf (WD) in a cataclysmic variable (CV) resembles a roller coaster. While still detached the WD cools like a single star, but as soon as mass transfer starts there are episodes of heating and cooling as either high mass transfer (\dot{M}) occurs through a stable accretion disc (i.e., as a nova-like variable) or episodically in a thermally unstable accretion disc (i.e., as a dwarf nova); and throughout its life the CV intermittently undergoes heating during the unstable thermonuclear burning that fuels nova eruptions.

Although the duty cycles of dwarf novae are directly observable, those of novae are in general not (the exception being recurrent novae, which is some extremum of a continuous distribution of nova recurrence times). There has been a lack of agreement between the theoretical mass ΔM ejected in a nova eruption and the observed mass of nova shells. Until recently, the most elaborate hydrodynamic and thermonuclear models gave $\Delta M \sim 2 \times 10^{-5} M_{\odot}$, whereas observational estimates are $\sim 2 \times 10^{-4} M_{\odot}$. This discrepancy has now probably been removed by the more careful consideration of the thermodynamic structure of accreting white dwarfs (Townsend & Bildsten 2003). Recalculation of CVs through entire nova cycles (as in Shara, Prialnik & Kovetz 1993) may now give nova recurrence times ($= \Delta M / \langle \dot{M} \rangle$) as functions of $\langle \dot{M} \rangle$ and M_{wd} which are closer to reality.

However, the estimate of the mean value $\langle \dot{M} \rangle$ between nova eruptions remains difficult. The great majority of novae are seen to erupt from a high \dot{M} state and return to the same state for at least 100 – 200 years after eruption (e.g. Warner 2002). Even though both mass and angular momentum are lost during an eruption, simple conservation laws require that the enhanced \dot{M} that occurs through post-eruptive irradiation of the companion by the heated WD be balanced by a lengthy stage of low \dot{M} (Kovetz, Prialnik & Shara 1988). Whether this is enough to drive the CV into a state of hibernation, with low or zero \dot{M} for great lengths of time, is disputed (e.g. Naylor 2002); it certainly does not seem to happen within the first couple of centuries after eruption, but the complete lack of success in finding the remnants of bright novae recorded in Oriental records of two or more millennia ago (Shara 1989), despite the fact that most modern naked eye novae end up as $m_v \sim 12 - 15$ remnants that are easily recognisable, provides the strongest evidence that hibernation on time scales $\sim 10^3$ y does indeed happen. Until indirect ways of estimating the duty cycle of this process are found, the value of $\langle \dot{M} \rangle$ will remain very uncertain.

Hibernating novae will appear as detached WD/M dwarf binaries in which the M dwarf almost fills its Roche lobe. Such detached systems are also responsible for the orbital period gap, according to the disrupted magnetic braking model (e.g. Verbunt 1984), and may not be distinguishable from those only temporarily at low \dot{M} because of a nova eruption. Outside the period gap, however, there should be no ambiguity, and it is therefore of interest that there are two CVs that have recently been recognised as hibernating systems – namely BPM 71214, with $P_{orb} = 4.84$ h, and EC 13471-1258 with $P_{orb} = 3.62$ d (Kawka & Vennes 2003; O’Donoghue et al. 2003). These are both relatively bright objects ($m_v = 13.6$ and 14.8 , respectively) and would be among the brightest nova-like variables in the sky if they currently had $\dot{M} \sim 10^{-8} M_\odot \text{ y}^{-1}$. Another object, LTT 329 at $m_v = 14.5$, with weak emission indicative of extremely low \dot{M} , has been known for some time (Bragaglia et al. 1990). None of these systems are close to the positions of ancient observed novae (Stephenson 1986).

Typical values of \dot{M}_v before and after eruption imply $\dot{M} \sim 10^{-8} M_\odot \text{ y}^{-1}$, which is an order of magnitude larger than what can be accounted for by magnetic braking alone; these are maintained for at least 200 y after eruption, but we do not know for how long these high rates may operate before eruption. The similar \dot{M}_v , and hence \dot{M} , pre- and asymptotically post-eruption has been explained as an irradiative feedback effect that generates an equilibrium high \dot{M} that prevents the WD from cooling below $\sim 50\,000$ K (Warner 2002). If there are ~ 500 y

of \dot{M} at ~ 10 times that dictated by magnetic braking (or GR angular momentum loss), then ~ 5000 y of zero or very low \dot{M} are required to redress the period of high living. These indicate the expected ratio of space densities of such systems, but such large numbers of low \dot{M} systems were not found in an initial search for hibernating CVs (Shara 1989).

However, the systematic discovery of fainter CVs (which is where the very low \dot{M} systems inevitably will be found) has begun in the output of the Sloan Digital Sky Survey, the first two releases of which are now available (Szkody et al. 2002a, 2003). Based on the spectra obtained for these ~ 50 new CVs, about 15% have such low \dot{M} values that the WD is easily detected in the visible spectrum. This is the type of survey that is needed to find very low \dot{M} systems – at least for CVs with short orbital periods where both the WD and its companion are intrinsically faint (very low \dot{M} systems of longer P_{orb} may be harder to recognise in the initial colour survey because they will look like ordinary K or M red dwarfs). With more complete surveys to even fainter limits it should become possible to estimate the true frequency distribution of \dot{M} , from which the \dot{M} duty cycle between nova eruptions will follow.

Sion (2003) has shown that the observed surface temperatures T_{eff} of the WDs in dwarf novae can be fully accounted for by the compressional heating that accompanies accretion. For the short orbital periods (i.e., below the orbital period gap) T_{eff} clusters around 15 000 K, which is close to what is predicted for GR-driven evolution. This result depends somewhat on the adopted WD masses. One importance of this result is that T_{eff} is an indirect way of learning something about $\langle \dot{M} \rangle$ and the \dot{M} duty cycle for dwarf novae.

The observed clustering of T_{eff} around 15 000 K, seen in the list given in Table 1 (based on Sion 2003), contains an observational bias – the stars on which it is based have almost all been found from dwarf nova outbursts, which have intervals that become very long for very low \dot{M} . For example, in Table 1 the lowest observed temperatures are correlated with the greatest intervals, T_{out} , between outbursts¹. There should be other, lower T_{eff} systems, with outburst intervals so long that they are unlikely to have been found via outbursts and are therefore absent from studies made hitherto. But these are the intrinsically faint CVs that are beginning to be found spectroscopically in the Sloan Survey.

This point appears most strongly in the known CV WD primaries that have non-radial oscillations. The ZZ Cet instability strip for isolated WDs lies approximately in the range 11 000 – 12 000 K. It may be modified to some extent in accreting WDs where the outer envelope has a different physical and chemical structure (see, e.g., Townsley &

Bildsten 2003). Until recently the only known CV/ZZ combination was GW Lib² (Warner & van Zyl 1998), which has $T_{eff} = 14\,700$ K according to Szkody et al. (2002b), indicating that the instability strip may be displaced blueward of that for isolated WDs. Note, however, that there are several dwarf novae in Table 1 that have measured T_{eff} similar to that of GW Lib, have detectable WD absorption lines in their spectra, and have been sufficiently observed photometrically in quiescence for ZZ Cet type oscillations to have been detected – without success. But they typically have outburst intervals ~ 1 y, which may be too short a time in quiescence for oscillations to grow in³. GW Lib, on the other hand, has had only one known outburst (in 1983: by which it was identified as a CV); this incidentally demonstrates that oscillations can appear within less than a decade after outburst.

The next CV/ZZ to be discovered was SDSS1610 (Woudt & Warner 2003), which was identified in the Sloan Survey first release as a very low \dot{M} system, and has had no known outbursts. On the basis of these two examples alone we are led to suspect that CV/ZZ stars are extremely low \dot{M} systems and their T_{eff} will be found to be lower than that currently accepted for GW Lib (and which in any case may have been overestimated).

Once well calibrated, the relative frequency of CV/ZZ systems will provide a valuable indicator of the number of CVs in the accreting WD instability strip, which is another means of studying the \dot{M} history of CVs. The first Sloan Survey release had just one CV/ZZ (SDSS 1610) out of 25 objects. The second release (Szkody et al. 2003) has four or five potential candidates out of 35 candidates, based on the visibility of the WD absorption spectra, but with only two of these having spectra very closely similar to GW Lib or SDSS1610 (i.e., rather than like the non-oscillating systems such as Z Cha and OY Car, which have more emission- filled absorption lines). Our observations (Warner & Woudt 2003) nevertheless show that SDSS0131 and SDSS2205 are certainly CV/ZZ stars – the fifth candidate has yet to be observed. A frequency $\sim 8\%$ among faint CVs is therefore indicated, which will give ~ 32 systems once the estimated 400 new CVs expected in the Sloan Survey (Szkody et al. 2002a) have been found and interrogated photometrically.

The four known CV/ZZ stars have hydrogen emission cores superimposed on the WD absorption lines. For somewhat lower \dot{M} the emission lines would not be so readily observable. It would be worth searching carefully for weak emission cores in known ZZ Cet stars – there could be a hibernating CV hidden among them.

Table 1 also includes T_{eff} measurements for polars, i.e., for the strongly magnetic WDs in CVs. Several of these have lower temperatures than

Table 1. White Dwarf temperatures in selected CVs.

<i>Star</i>	P_{orb} (min)	T_{eff} (K)	T_{out} (d)	<i>References</i>
Non-magnetic				
GW Lib	76.8	13 300	>7000	Szkody et al. 2002b
BW Scl	78.2	14 800		Szkody et al. 2002c
LL And	79.8	14 300	5000:	Howell et al. 2002a
AL Com	81.6	16 300	325	Szkody et al. 2003
WZ Sge	81.6	15 000	10000:	Sion et al. 1995a
SW UMa	81.8	14 000	954	Gaensicke & Koester 1999
HV Vir	83.5	13 300	3500:	Szkody et al. 2002c
WX Cet	84.0	13 000	1000:	Sion et al. 2003
EG Cnc	86.3	12 300	7000:	Szkody et al. 2002c
BC UMa	90.1	15 200	1500:	Szkody et al. 2002c
EK TrA	90.5	18 800	230	Gaensicke et al. 2001
VY Aqr	90.8	13 500	500:	Sion et al. 2003
OY Car	90.9	16 000	160	Horne et al. 1994
HT Cas	106.1	15 500	166:	Wood et al. 1992
VW Hyi	107.0	22 000	28	Sion et al. 1995b
Z Cha	107.3	15 700	51	Robinson et al. 1995
CU Vel	113.0	15 000	165	Gaensicke & Koester 1999
EF Peg	123	16 600	250:	Howell et al. 2002a
Polars				
EF Eri	81.0	9 500		Howell et al. 2002b
DP Leo	89.8	13 500		Schwope et al. 2002
VV Pup	100.4	9 000		Szkody et al. 1983
V834 Cen	101.5	15 000		Beuremann et al. 1990
BL Hyi	113.7	20 000		Wickramasinghe et al. 1984
ST LMi	113.9	11 000		Mukai & Charles 1986
MR Ser	113.6	<8 500		Schwope & Beuremann 1993
AN UMa	114.8	<20 000		Sion 1991
HU Aqr	125.0	<13 000		Glenn et al. 1994
UZ For	126.5	11 000		Bailey & Cropper 1991
AM Her	185.7	~20 000		De Pasquale & Sion 2001
RXJ1313	251.4	15 000		Gaensicke et al. 2000

: Uncertain value

any seen in dwarf novae. Some have T_{eff} that could put them in the instability strip. Most of these are the brightest and best-observed polars, but none have been found to have ZZ Cet behaviour. Theoretical investigations are needed that include the effects of strong fields, which will presumably be found to prevent non-radial oscillations above some critical field strength.

The low T_{eff} in the longer P_{orb} polar RXJ1313 implies a much lower $\langle \dot{M} \rangle$ than is the case for the commonly observed non-magnetic CVs at that P_{orb} . Again there may be an observational bias in action – polars even of low \dot{M} are easily found through their hard X-Ray emission, whereas the comparative rarity of low \dot{M} dwarf novae near P_{orb} of 4 h is probably caused by the effect of irradiation-enhanced \dot{M} , which turns them either into high \dot{M} nova-likes, or into extremely low \dot{M} dwarf novae (or even deeply hibernating, essentially zero \dot{M} systems, as in the BPM and EC objects discussed above) that are hard to find (Wu, Wickramasinghe & Warner 1995).

Finally, we draw attention to the AM CVn (helium-transferring CV) systems, where the WD primaries could in principle show non-radial oscillations if they are in the equivalent of the DB variable instability strip. These would have to be found among AM CVn stars that have an appropriate \dot{M} – but that is in just the range where these systems show VY Scl behaviour, and in the high state the accretion luminosity will overwhelm any intrinsic pulsations of the primary, while in the low state \dot{M} is probably too variable to give the oscillations time to grow.

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Notes

1. WZ Sge appears not to fit this correlation, but it has a magnetic primary, which is probably the reason for the large T_{out} (e.g. Warner, Livio & Tout 1992).
2. This ZZ Cet star is overlooked in the total given by Fontaine et al. (2002) and Bergeron et al. (2003).
3. Growth times for non-radial oscillations in ZZ Cet stars can be anywhere from hours to thousands of years, according to which mode is being excited (Goldreich & Wu 1999).

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